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Resonant X-ray Scattering from a Magnetic Multilayer Reflection Grating

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Magnetic multilayers exhibit a very diverse range of fundamental phenomena that underpin much of the data-storage technology we now rely upon, and are of great interest in the emergent technology of spin-electronics. Recently, techniques have allowed the patterning of such systems so that all three spatial dimensions are accessible and controllable at the nanoscale, but it is important to determine how the magnetic microstructure responds to the physical structures imposed upon it. Using soft x-ray magnetic resonant scattering we have studied this behaviour in a system in which the physical structure was deliberately patterned to observe the response of the magnetism to such a perturbation. We found that the magnetisation only tracks the highest Fourier components of the physical structure effectively.

It is well known that the competition between the interaction energies in a ferromagnetic material may lead to the formation of magnetic domains — regions in which there is microscopic ordering of the electron spin to minimise the free energy. If we then impose a physical in-plane pattern on this system, we will have additional competition introduced through the physical shape of the magnetic element. Such a situation has led to the proposal to use patterned arrays to provide ultra-high magnetic storage densities and move beyond the super-paramagnetic limit, in which the magnetic structure becomes thermally unstable (>100Gb/in^2).

To more fully understand this interaction we have prepared antiferromagnetically coupled multilayers of cobalt/ruthenium (Co/Ru) with a nominal structure [Co(4nm)/Ru(3.4nm)]$_{x10}$ on top of a polystyrene (PS) line array. The array was produced by micro-contact printing, in which a mold is pressed into the PS at a pressure of 10 kPa to produce a line array with a 400 nm period and a 1:1 mark/space ratio. The advantage of such a technique is that large-area patterning is readily achievable. A scanning electron micrograph of the completed sample is shown in **Figure 1**.

Numerous techniques exist to study the structural morphology of multilayers. However, studying the magnetic structure of the *buried* layers of this patterned Co/Ru multilayer requires a scattering technique such as soft x-ray resonant magnetic scattering (XRMS). By tuning the incident photon energy to the L_{III} absorption edge of the Co (778eV) we can observe both structural morphology and the cross-correlation of the magnetic structure with the physical structure. The diffraction pattern from such a grating structure is shown in **Figure 2a**. In the XRMS measurement we can either change the helicity of the circularly polarized photons or reverse the magnetization of the sample (curves I_+, I_- in **Figure 2a**). The sum of these two data (**Figure 2b**) is related to the self-correlation of the physical structure whilst the difference is sensitive to the cross-correlation of the physical and magnetic structures. A very sensitive measure is then to plot the asymmetry ratio $(I_+-I_-)/(I_++I_-)$ (**Figure 2c**). Only the first harmonic is present in **Figure 2c**, clearly showing that the magnetic in-plane wave form is significantly different from that of the structural one. The

results suggest that the magnetic structure only tracks the gross features of the physical structure, *i.e.* the fundamental period of the physical grating. However, it does not track the finer details that are present in the structural data as higher order harmonics (**Figure 2b**), but are very weak in the asymmetry ratio (**Figure 2c**).

We are complementing these measurements by using polarized neutron scattering, magnetic microscopy, and micromagnetic simulations. This apparent smoothing of the magnetic structure must be accounted for in any patterned recording media based on this type of technology.
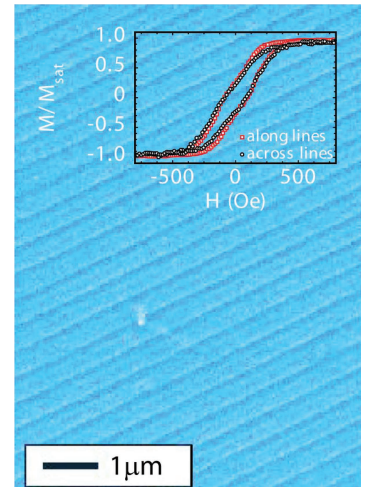
Figure 1. A scanning electron micrograph of the multilayer-coated PS line array. The inset shows the magnetization loop, measured by MOKE, parallel and perpendicular to the line direction. Parallel to the lines is a slightly easier magnetization axis.
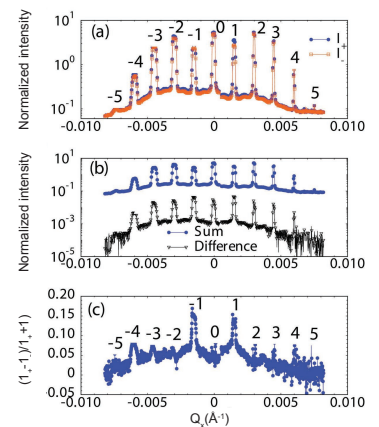
Figure 2. (a) The diffraction pattern from the PS line array. Q_x is the in-plane momentum wave-vector transfer (parallel to the sample surface). The two curves represent the magnetization of the sample. (b) The average and difference of the data presented in panel (a). (c) The asymmetry ratio as defined in the text showing the strong suppression of the higher-order Fourier harmonics.